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Introduction to Air Quality Modeling. A Report of the NATO/CCMS Pilot Study on Air Pollution Assessment Methodology and Modeling

NATO Committee on the Challenges of Modern Society, Brussels (Belgium)

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THE CHALLENGES OF
MODERN SOCIETY

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ASSESSMENT METHODOLOGY and MODELLING

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The purpose of this report is not to give a detailed review of the existing air quality models but to review the methods used for modeling, in particular for models to be us in AQMS, in order to give indications where they could preferably be applied, to state their advantages and disadvantages and summarize the problems connected with the application of models.

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Introduction to
Air Quality Modeling

A Report of the NATO/CCMS Pilot Study
on Air Pollution Assessment Methodology and Modeling

COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY
NORTH ATLANTIC TREATY ORGANIZATION
October 1978

Preface

The North Atlantic Treaty Organization (NATO) established the "Committee on the Challenges of Modern Society" (CCMS) at the November 1969 meeting of the North Atlantic Council.

The CCMS was charged with developing meaningful environmental and social programs that complement other international programs, and with showing leadership, first, in solution of existing problems and, second, in development of long-range goals for environmental protection in the NATO sphere of influence and in other countries as well. A first Pilot Study on Air Pollution was initiated by the CCMS at its inaugural meeting in December 1969. The United States (Environmental Protection Agency) has been the pilot nation with the Federal Republic of Germany (Federal Ministry of the Interior) and Turkey (Scientific and Technical Research Council) as copilot-nations.

The Pilot Study on Air Pollution was an action program designed to demonstrate and encourage the utilization of existing knowledge for the development of air quality management programs. It entailed the demonstration of a system approach to air quality management. Case studies have been carried out in Ankara, Turkey; Frankfurt, Federal Republic of Germany; St. Louis, U. S.; Oslo, Norway; South Holland Region, The Netherlands (NATO/CCMS Report No. 6, Appendices A - E).

The results of the pilot study are documented in NATO/CCMS Report No. 6 (Revised) "Guidelines to Assessment of Air Quality" of October 1972 and in NATO/CCMS Report No. 33 (Final Report) containing 15 recommendations as well as in several other documents, listed as Annex II to this document.

Starting from three of the above recommendations (VI, VII and XIV) the Federal Republic of Germany proposed to initiate a new Pilot Study on Air Pollution Assessment Methodology and Modeling at the CCMS Plenary Session on October 22 and 23, 1974.

These NATO/CCMS Recommendations are:

RECOMMENDATION IV

Member nations will co-operate to develop standardized methods for emissions data storage and retrieval to support requirements in the conduct of national air quality management programs. The US National Emission Data System (NEDS) might serve as a model for a common international system.

RECOMMENDATION VII

Member nations will co-operate to develop standardized techniques for projecting emissions and predicting future ambient air quality.

RECOMMENDATION XIV

Member nations agree the CCMS modeling activity has shown that there is a widespread need for further international co-operation to accomplish the following tasks:

- Bring together model developers and air quality managers for exchange of ideas, discussion of users' needs and demonstration of modeling techniques.
- Standardize modeling techniques for specific air quality management applications and consider how computerized models might be made available for all users.
- Continue to review on-going air quality assessment studies.

In spring 1973 the North Atlantic Council approved the German proposal. The pilot study work started with the Federal Republic of Germany (Federal Ministry of the Interior) as pilot nation and the United States of America (Environmental Protection Agency) and Belgium (Service du Premier Ministre) as co-pilot nations:
A Working Group and two Panels were established with the following functions:

Assessment Methodology Panel

- Pursue and carry out Recommendations VI and VII
- Continue to review present and future assessment studies with respect to the application of assessment methodology.

Modeling Panel

- Develop standardized models for various air quality management applications.
- Develop programs to improve modeler/user communications in conjunction with the Assessment Methodology Panel and the Working Group.
- Continue as an information forum on new modeling concepts and techniques, organizing once a year international technical meetings on air pollution modeling and its application.

In addition the Working Group established an Ad-Hoc Group on Air Quality Management Systems to revise and update the NATO/CCMS Report No. 6 (Revised) 1972 by preparing a new document on "Guidelines to Air Quality Management Systems".

Another Ad-Hoc Group was set up for compiling a Glossary of Terms frequently used in assessment methodology, modeling and air quality management systems.

As an outcome of this Pilot Study on Air Pollution Assessment Methodology and Modeling the following NATO/CCMS documents are published (see also Annex III):

Air Quality Management System

- Guidelines to Air Quality Management System.

Assessment Methodology

- Air Pollution Emission Inventory Systems
- Air Pollution Emissions Projecting

Air Pollution Modeling

- Introduction to Air Quality Modeling
- Uses and Needs for Air Quality Modeling
- Bibliography on Grey Literature on Air Quality Modeling, Part I (Applied Models)
- Bibliography on Grey Literature on Air Quality Modeling, Part II (New Modeling Techniques)
- Practical Demonstration of Multiple Source Urban Air Quality Modeling (Gaussian Plume)
- Fundamentals for the Applications of a Gaussian Plume Model

Other Publications

- Glossary of Terms
- Proceedings of the 6th International Technical Meeting on Air Pollution Modeling and its Application (24. - 26. September 1975, Frankfurt/Main, Germany)
- Proceedings of the 7th International Technical Meeting on Air Pollution Modeling and its Application (7. - 10. September 1976, Airlie House, USA)
- Proceedings of the 8th International Technical Meeting on Air Pollution Modeling and its Application (20. - 23. September 1977, Louvain-la-Neuve, Belgium).

The chairman of the Working Group wishes to acknowledge the scientists participating from pilot, copilot, and observer countries, and the many other persons, who assisted in the preparation of this document.

The panel, which performed diligently throughout the course of this effort, receives the highest praise. The panel members were:

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Full recognition is given to each panel member for carrying out and coordinating review and other activities related to the development of this document in his respective country and to Ms. C. Morawa of the Federal Environmental Office, Germany for her effort in coordinating and organising and for editorial work.

For the Working Group,
Erich Weber, Chairman.

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1. Aims and goals of Air Quality Modeling (AQM)

The goal of AQ Modeling is to supply pertinent information for decisions made within the framework of AQ Management Systems, especially in connection with control strategies. The fundamental problem which has to be solved within an AQM is to calculate air concentrations of one or more species in space and time as related to the independent variables such as the emissions into the atmosphere, the meteorological variables, and such parameters which describe removal and transformation processes. All these independent variables can be functions of space and time, but need not all be considered. If these air concentration fields are calculated as functions of space and time one can obtain from them hourly, daily, monthly or yearly averages or frequency distributions of concentrations at a given point in the field, which in most cases will be at the surface. This aim is achieved by a system, which relates quantitatively the concentrations to the other parameters by mathematical and/or physical methods. Such a procedure is called a "model".

It is very important to note here that the type of information which is needed for the decisions in the AQMS determines to a large extent what type of model is to be used. But not only the type of information which is used from the output of a model determines model type and sophistication but also the type and amount of input information which is available has a great influence on the selection of a model. It is therefore strongly advised that the potential user of model results should get as early and as deeply as possible into contact with a person who has experience with modeling and can advise on the selection of a particular model.

The purpose of this introduction is not to give a detailed review of the existing models but to review the methods used for modeling, in particular for models to be used in AQMS, in order to give indications where they could preferably be applied, to state their advantages and disadvantages and summarize the problems connected with the application of models.

2. Air Quality Models (AQMs)

General Remarks

The principal subdivision which is made in this text is that between deterministic, statistical and physical models. According to this subdivision a deterministic model is one which calculates the concentrations from an emission inventory and other independent, mostly meteorological variables according to the solution of various equations that represent the relevant physical processes. In contrast to the deterministic model the statistical one calculates concentrations by statistical methods from meteorological and other parameters after the statistical relationship has been obtained empirically from measured concentrations. An emission inventory is not needed. The physical model is a model, in which nature is simulated on a smaller scale in the laboratory, e. g. in a windtunnel.

The deterministic model is most suitable for long term planing decisions. The statistical model is very useful for short term forecasts of concentrations and the physical model may then be of use, if only influences of topography or high buildings in the surroundings of large sources have to be considered. Unfortunately, the last model type is seldom employed to give quantitative results in the above sense and is therefore rarely used in AQ Modeling.

2.1 Deterministic Models

Most of the deterministic models use or are equivalent to using solutions of the diffusion equation. The diffusion equation is based on the principle of conservation of mass. The turbulent fluxes of material are expressed by the gradient relationship, i. e. it is assumed that the turbulent flux is proportional to the gradient of concentration and the proportionality "constant" is called the diffusion coefficient. The diffusion equation reads as follows:

$$\frac{\partial \bar{s}}{\partial t} + \bar{u}\frac{\partial \bar{s}}{\partial x} + \bar{v}\frac{\partial \bar{s}}{\partial y} + \bar{w}\frac{\partial \bar{s}}{\partial z} = \frac{\partial}{\partial x}\left(k_x \frac{\partial \bar{s}}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial s}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial s}{\partial z}\right) \tag{1}$$

+ source terms + transformation terms.

The symbols have the following meaning:

$\bar{s}$	= the time averaged concentration
x,y,z	= the cartesian coordinates
$\bar{u},\bar{v},\bar{w}$	= the components of the time averaged wind vector
k_x,k_y,k_z	= the diffusion coefficents in the corresponding directions.

If the earth's surface is horizontal and no buoyancy effects are taken into account, the vertical component of the time averaged wind vector is zero and the last term on the left hand side of (1) vanishes. Furthermore, if diffusion is only considered in the lowest, approximately 100 meters of the atmosphere, wind direction does not change with height and the coordinate system can be directed with its x-axis into the direction of the flow. From that it follows that $\bar{v} = 0$ and the third term of the left hand side of (1)

vanishes. For wind velocities greater than ca. 1 m/sec, the following inequality holds

$$\bar{u} \frac{\partial \bar{s}}{\partial x} \gg \frac{\partial}{\partial x} \left(K_x \frac{\partial s}{\partial x} \right) \qquad (2)$$

and the first term of the right hand side of (1) is neglected according to (2).

Apart from the problems connected with the solution of the (parabolic) partial differential equation the main problem is to obtain the meteorological parameters of (1), i. e. the wind vector and the diffusion coefficients, which are in general functions of space and time. The wind vector can be measured by methods well known (although to get these measurements as function of space and time in a required density involves large efforts). The greater problem is to state the diffusion coefficients, since they cannot be measured directly. In fact, they can only be determined a posteriori, i. e. from simultaneous flux- and gradient-measurements, and are then applied for situations, where one assumes that the flow characteristics are the same as in the case where measurements were made.

The boundary conditions at the earth's surface have to be stated and it is often assumed that the diffusing material (gases) is not absorbed by the ground, i. e. the material is "reflected" into the atmosphere. The other extreme case, that all material reaching the surface is absorbed, is not appropriate at least for gases and very seldom used. Partial reflection of the material at the ground is the most realistic case but it involves the statement of another parameter, which is usually called the deposition velocity, and only recently have reliable values been obtained by experiments.

Often a boundary condition for the upper boundary of the diffusion volume is stated, especially in case of an inversion. In that case too the total reflection assumption at the upper boundary is used.

The models calculate the concentration at one receptor point from one source. If more than one source is present then the contributions from each source at the receptor point are summed. Only for the simplest assumptions of the meteorological parameters analytical solutions of the diffusion equation exist. For a realistic modeling it is therefore unavoidable to solve the diffusion equation numerically.

2.1.1 Steady State Models

The steady state condition implies that all variables and parameters are constant in time. This includes the concentration, i. e. $\frac{\partial s}{\partial t} = 0$. However, steady state solutions are often obtained with the time dependent equation ($\frac{\partial s}{\partial t} \neq 0$), but with all meteorological and other parameters kept constant. One then calculates forward in time until the steady state is reached for the concentration. Therefore, the models mentioned under 2.1.2 can also be used for steady state modeling. Steady state models - by the nature of the inherent assumptions of the time constancy of the parameters - can be applied only for shorter distances (order of 10 km) and of shorter travel times (order of 2 hours).

2.1.1.1 The Gaussian Model

The most widely used model in AQMS is the Gaussian Model, which is a steady state model. The term Gaussian Model originates from the fact, that the vertical and horizontal (perpendicular to the mean wind direction) concentration distributions are Gaussian normal distributions, the standard deviations σ_y and σ_z of which are functions of source distance and the meteorological situation. These σ-values and -functions have been obtained by diffusion experiments in the atmosphere and are related through so-called diffusion categorys schemes (for example that of Pasquill's) to easily measured meteorological (surface) parameters. Although there is still some discrepancy about the way to find the best set of σ-values for a particular problem, this model is widely used, because it is rather simple and easy to handle.

The Gaussian concentration formula for a plume is an analytical solution of the simplified diffusion equation in case of a continuous point source

$$\bar{u}\,\frac{\partial \bar{s}}{\partial x} = k_z \frac{\partial^2 \bar{s}}{\partial z^2} + k_y \frac{\partial^2 \bar{s}}{\partial y^2} \qquad (3)$$

with the relation

$$\sigma_i^2 = \frac{2 k_i}{\bar{u}} x \qquad i = y, z \qquad (4)$$

Besides the assumption that $\bar{u}$, k_z and k_y are constants (also with height) it is usually assumed that the material is reflected at the earths surface. Area sources are often simulated by a larger number of point sources distributed equally over the source area. Solutions for an infinite and a finite line source exist also.

In order to comply with the assumption inherent in the model that $\bar{u}$ = const. in most models a vertically averaged wind profile is introduced.

2.1.1.2 Other Models

As mentioned before all time dependent models under 2.1.2 can be used as steady state models.

2.1.1.3 Simple Model

One extremely simple model for the calculation of concentrations from area sources ("ATDL-Model") has been given, where the concentration is proportional to the source strength and inversely proportional to the mean wind speed. The proportionality constant depends on stability, mixing height and city size. But even with an average proportionality constant empirically obtained the model gives satisfactory results.

2.1.2 Time-dependent Models

In a time dependent model all variables can be functions of time and the concentration is calculated depending on time. With a relatively few exceptions all time dependent models go back in principle to a solution of the diffusion equation (1), but formulations and solution methods differ. The box models and the grid models are the models most widely used.

2.1.2.1 Box Models

In a box model the atmosphere is divided into a number of boxes of given length, width and height. In each of the boxes the concentration is assumed to be constant. For each box a budget equation is solved for each time step taking into account the fluxes of material across the boundaries of the boxes (advective and turbulent), sources, sinks, sedimentation, deposition, transformation etc. Such a box model is graphic, easy to formulate and relatively easy to handle.

2.1.2.2 Grid Models

The grid model solves the diffusion equation after it has been transformed into a finite difference equation in Eulerian space. The concentration values are obtained at the grid points and are averages in time and space according to the chosen time step and grid size.

The large number of existing grid models differ with respect to

1. resolution in time and space
2. formulation of the finite differences
3. treatment of sources and sinks
4. treatment of and assumptions on meteorological parameters
5. division into horizontal and vertical diffusion
6. methods to avoid numerical diffusion
7. inclusion of chemical reactions and transformations.

Grid models and also box models are mostly used for the simulation of episodes, because the computational effort connected with their application is large. In fact it is so large that the computation of, say, hourly values for an extensive time period like a year or more is very time consuring. Usually simulation times greater than a few days cannot be afforded. A combination of grid- or box models on one hand and statistical models on the other seems a promising way of studying emission and meteorological effects seperately or for long term planning, if a measuring network exists.

2.1.2.3 Spectral Models

The spectral models differ from those under 2.1.2.2 in that the diffusion eqation is transformed into Fourier space and then solved. The advantage here is that one avoids numerical truncation errors. There does not seem to be an advantage in computational effort.

2.1.2.4 Lagrangian and Random Walk Models

In a Lagrangian model individual air parcels are followed and the concentration computed for each parcel. Numerical diffusion is avoided, but the disadvantage is that very large computer storage and time is needed. The same is true for random walk models, where particles perform a random walk in grid space with prescribed transition probabilities. Because of the computer economics involved both models do not seem to be applicable when frequency statistics of concentrations are needed.

2.1.2.5 Trajectory Model

The trajectory model is a special type of Lagrangian model, where the trajectory of the center of gravity of a diffusing cloud is computed first and then the diffusion with respect to this center of gravity is taken into account. Again, large computational effort is required for a multiple source model. It seems however to be applicable for short term forecasts in connection with dangerous, unintentional releases of material, e. g. in the case of an accident.

2.2 Statistical models

Statistical models as defined before relate measured concentrations at one point or from a measuring network to simultaneously measured variables, such as meteorological parameters, time of day or year, etc. The so obtained statistical relationship is used for forecasting the concentrations for a given set of the above variables. The emission characteristics, however, must not change between the time of measurements and the application time, i. e. no additional sources can be added or the existing sources can not change their time-dependent behaviour. The advantage of such models is their small computational effort and that they simulate measured concentrations (see 2.2.1) fields or concentration (see 2.2.2). No emission inventory is needed. The disadvantage besides the one already mentioned is that concentration measurements are needed. They seem especially suitable for short term forecasts in an area where concentration values are measured. They can also be used to take into account background concentrations in a deterministic model.

2.2.1 Regression Model

This simple model relates measured concentrations at one point to meteorological variables. It has not been used widely, since its usefulness is very limited.

2.2.2 Empirical Orthogonal Functions

In this model measured concentration values at a number of stations are related by statistical methods to pertinent meteorological variables and time. The mathematical method employed uses Eigenvector and -coefficients for the concentration correlation matrix. This method is relatively simple and fast.

2.3 Physical Models

As already mentioned under 2. the physical model will simulate nature on a smaller scale, i. e. in the laboratory in a wind - or water tunnel. It is in general, not used in AQ modeling with the exception of studies of influences of topography and high buildings in the surroundings of large sources.

3. Problems connected with AQ Modeling

3.1 Time and Space Averaging

Numerical models average the concentration values in space and time according to the time step and grid spacing or box size employed in the model. The measurements on the other hand give also time averaged, but mostly not space averaged concentrations. The calculated and measured concentrations are then not immediately comparable. This will be especially pronounc-

ed in areas with steep concentration gradients. It is therefore a problem how to compare these two values. Furthermore, grid spacing or box sizes must be in accordance with the grid size of the emission inventory. It is therefore not sensible, to calculate concentrations in a grid that is smaller than that of the emission inventory. Large single sources have often to be treated in a special way.

3.2 Input Data

There are many problems connected with any type of input data. It is often advisable to perform sensitivity analysis with a model in order to study the influence of each input parameter on the results. From this analysis one can determine or estimate which input parameters have to be known to which degree of precision.

3.2.1 Emission Data

Usually the emission data are not detailed enough in space and time. This is because a large effort is necessary to compile an emission inventory even with its simplest characteristics. Especially the changes of the source behaviour as function of time are not known in detail. One is also forced to treat the large number of small sources - for example those from domestic heating or from automobiles - in a simplifying manner, that one assumes area sources for the domestic heating or line sources for automobiles. These simplifying assumptions introduce error possibilities.

3.2.2 Meteorological Data

Again, the meteorological data will in many cases not be dense enough in space and time to supply to a model the input parameters in a satisfying manner. Mostly, only surface values of the meteorological parameters are available and the turbulence characteristics in the boundary layer of the atmosphere must be estimated from surface data. Even if vertical profiles of temparature and wind are measured at one or several places the time intervals between measurements are a few to several hours and the values in between have to be estimated. Another problem is how to determine from the vertical profiles the diffusion coefficients needed in the model. To sum up it is very seldom that enough meteorological data are available for application of AQMs on a climatological basis, i. e. to compute hourly concentration values 24 hours a day throughout a whole year.

3.2.3 Plume Rise

The height of the emission of material is very important for the surface concentration values. In many cases this height is not identical with the height of release because the plume rises due to density differences to its surroundings and momentum excess. There exist a large number of formulae which try to describe the plume behaviour, but they differ considerably in their results and it is still controversial which formula is "the best". The plume rise value is rather sensitive to the temperature stratification in the boundary layer and measurements of vertical temperature profiles are not always available.

3.3 Representation of Results

There is no standard way in which the results of a AQM are presented. Preferably two dimensional concentration fields in the way of isolines of mean values, 95 percentiles, etc. should be given. Also frequency distributions or cumulative frequency distributions of concentrations at a given location are helpful.

3.4 Calibration of Models

The idea which is behind this terminology is to compare model results with measured concentrations and that one can obtain one or several empirical factors which bring calculated and measured values in agreement. Usually this does not work because the results depend on so many parameters that it is not possible to determine one or even several factors which improve the results under all circumstances. In addition, even if there is such a factor or factors which have been determined from past measurements these factors might not be correct for the future.

3.5 Verification of Models

The quantitative description of model performance presents problems. Correlation coefficients averaged in space or time describe only a linear relationship. Mean ratios of calculated to observed concentrations can distort the picture. The same is true for the standard error of estimate, because there is a large variation of orders of magnitude in the concentrations values. The suggestion which is made here is that as many as possible of the statistical performance measures should be given.

3.6 Transformation and Removal Processes

For large distances (greater than ca. 10 km) or large travel times (more than few hours) transformation and removal processes become important. In a few cases (automobile exhausts) even for very small travel times the transformation process has to be considered. Apart from the fact that deterministic modeling becomes more and more difficult when these processes are included - the computational effort will increase considerably - there are not enough data on rate coefficients and their behaviour in the atmosphere. Therefore, the modeling of the mentioned type of processes is still in its beginning and research work is strongly needed.

3.7 Topographic influences

The topography and orography in the area where AQM is applied influence strongly the meteorological parameters and through them the concentration field. Typical examples are sea breeze and mountain effects. A combination of mesoscale meteorological models with AQM can give insight in the magnitude of these effects. This type of study is still in the research stage. But since large computer storages and times are required for those calculations it is not foreseen that AQMS can rely in the near future on this type of combined modeling.

ANNEX I

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ANNEX II

NATO/CCMS Documents on the First Air Pollution Pilot Study (available at: NATO/Committee on the Challenges of Modern Society, NATO Headquarters, Brussels, Belgium)

AIR POLLUTION (No. 5)

Proceedings of the 2nd Meeting of the Expert Panel on Air Pollution Modeling, (26 - 27 July 1971, Paris, France) Out of stock

AIR POLLUTION (No. 6)

Guidelines to Assessment of Air Quality (Revised)

APPENDIX A	Assessment of Air Quality in Ankara (February 1973)
APPENDIX B	Assessment of Air Quality in St. Louis (February 1973)
APPENDIX C	Assessment of Air Quality in Frankfurt (June 1974)
APPENDIX D	Assessment of Air Quality in Oslo (February 1973)
APPENDIX E	Assessment of Air Quality in South Holland Region (December 1973)

AIR POLLUTION (No. 7)

Quality Criteria for Sulphur Oxides (November 1971) Out of stock

AIR POLLUTION (No. 8)

Air Quality Criteria for Particulate Matter (November 1971) Out of stock

AIR POLLUTION (No. 10)

Air Quality Criteria for Carbon Monoxide (June 1972)

AIR POLLUTION (No. 12)

Control Techniques for Sulphur Oxide Air Pollutants (October 1975)

AIR POLLUTION (No. 13)

Control Techniques for Particulate Air Pollutants
(October 1973)

AIR POLLUTION (No. 14)

Proceedings of the 3rd Meeting of the Expert Panel on Air Pollution Modeling
(2 - 3 October, 1972, Paris)

AIR POLLUTION (No. 15)

Air Quality Criteria for Nitrogen Oxides (June 1973)

AIR POLLUTION (No. 18)

Control Techniques for Carbon Monoxide Emissions from Stationary Sources (October 1973)

AIR POLLUTION (No. 19)

Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources (October 1973)

AIR POLLUTION (No. 20)

Control Techniques for Nitrogen Oxide Emissions from Stationary Sources (October 1973)

AIR POLLUTION (No. 29)

Air Quality Criteria for Photochemical Oxidants and Related Hydrocarbons (February 1974)

AIR POLLUTION (No. 30)

Proceedings of the 4th Meeting of the Expert Panel on Air Pollution Modeling, (28 - 30 May 1973, Oberursel, Germany)

AIR POLLUTION (No. 33)

Final Report (May 1974)

AIR POLLUTION (No. 35)

Proceedings of the 5th Meeting of the Expert Panel on Air Pollution Modeling (4 - 6 June 1974, Roskilde, Denmark)

AIR POLLUTION (No. 41)

First Follow-up Report (December 1975)

AIR POLLUTION (No. 50)

Second Follow-up Report (December 1976)

AIR POLLUTION (No. 67)

3rd Follow-up Report (November 1977)

Annex III

NATO/CCMS Documents on the Pilot Study on Air Pollution Assessment Methodology and Modeling
(available at: NATO/Committee on the Challenges of Modern Society, NATO Headquaters, Brussels, Belgium)

Air Pollution (No. 42)

Proceedings of the 6th International Technical Meeting on Air Pollution Modeling and its Application
(24 - 26 September 1976, Frankfurt/Main, Germany)

Air Pollution (No. 51)

Proceedings of the 7th International Technical Meeting on Air Pollution Modeling and its Application
(7 - 10 September 1976, Airlie House, USA)

Air Pollution (No. 70)

Bibliography on Grey Literature on Air Quality Modeling, Part I (Applied Models)

Air Pollution (No. 71)

Air Quality Management Systems

Air Pollution (No. 88)

Bibliography on Grey Literature on Air Quality Modeling, Part II (New Modeling Techniques)

Air Pollution (No. 89)

Glossary of Terms Generally Used in Air Pollution Assessment Methodology and Modeling

Air Pollution (No.)

Proceeding of the 8th International Technical Meeting on Air Pollution Modeling and its Application
(20 - 23 September 1977, Louvain-la-Neuve, Belgium)

Air Pollution (No.)

Air Pollution Emission Projecting

Air Pollution (No.)

Introduction to Air Quality Modeling